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(54) **METHOD USING MAGNETOSTRICTIVE PROBE BUOYANCY FOR DETECTING FUEL DENSITY**

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4,977,528 A	12/1990	Norris	
5,017,867 A *	5/1991	Dumais et al.	73/314 X
5,050,430 A *	9/1991	Begin et al.	73/313 X
5,076,100 A	12/1991	Hunter et al.	
5,136,884 A *	8/1992	Lovett	73/313
5,193,912 A	3/1993	Saunders	
5,319,545 A	6/1994	McGarvey et al.	

(Continued)

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(52) **U.S. Cl.** **702/25; 73/291; 73/306; 73/447**

(58) **Field of Classification Search** **702/25; 73/447, 291, 306, 309, 313-314**
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,620,661 A *	12/1952	Roux	73/313
2,911,828 A	11/1959	Keating et al.	
4,155,254 A	5/1979	Colditz	
4,193,303 A	3/1980	Egnell	
4,625,553 A	12/1986	Charter	
4,924,700 A	5/1990	Habart	
4,943,773 A *	7/1990	Koski et al.	73/314 X
4,952,873 A *	8/1990	Tellerman	73/314 X

FOREIGN PATENT DOCUMENTS

WO 2004013583 2/2004

OTHER PUBLICATIONS

Veeder-Root, "Mag 1 & 2 Plus! Probes Assembly Guide," Manual No. 577013-744, Revision C, 2003, 10 pages.

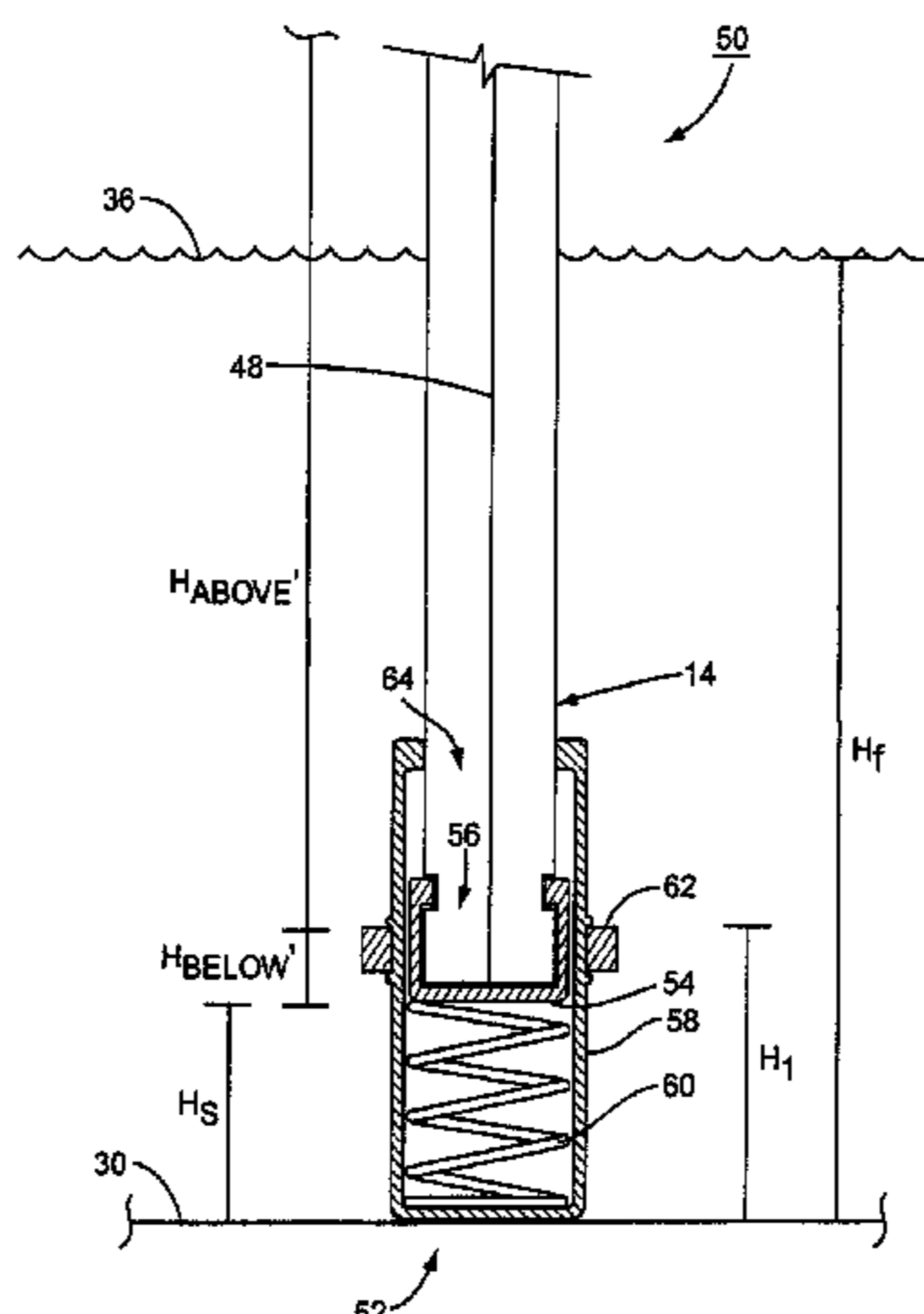
(Continued)

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(57) **ABSTRACT**

A magnetostrictive fuel level probe includes a spring-loaded foot. The probe shaft of the fuel level probe moves up and down within the spring-loaded foot as a function of fuel density. The spring-loaded foot includes a reference magnet whose height relative to the bottom of a fuel storage tank is fixed. Currents generated by the fuel level probe allow measurement of how much of the fuel level probe is positioned above the reference magnet, and from this measurement, the buoyancy of the fuel level probe may be measured. From the buoyancy of the fuel level probe, the fuel density may be calculated.

10 Claims, 6 Drawing Sheets



U.S. PATENT DOCUMENTS

5,400,253 A 3/1995 O'Connor
5,412,316 A * 5/1995 Dumais et al. 73/314 X
5,423,457 A 6/1995 Nicholas et al.
5,471,873 A 12/1995 Nyce et al.
5,473,245 A * 12/1995 Silvus et al. 73/314 X
5,640,880 A * 6/1997 Mulrooney et al. 73/313
5,734,851 A 3/1998 Leatherman et al.
5,814,830 A * 9/1998 Crowne 73/314 X
5,848,549 A 12/1998 Nyce et al.
5,956,259 A 9/1999 Hartsell, Jr. et al.
6,052,629 A 4/2000 Leatherman et al.
7,278,311 B1 * 10/2007 Demin 73/313 X
2004/0093942 A1 5/2004 Brun
2006/0048569 A1 3/2006 Manfiotto et al.
2006/0169039 A1 * 8/2006 Zalenski et al. 73/290 R
2006/0248952 A1 11/2006 Jarvie

2007/0295085 A1* 12/2007 Demin 73/447

OTHER PUBLICATIONS

Setra, "Model 201 Pressure Transducer; Very Low Differential Gauge Pressure," from <http://www.setra.com>, Nov. 2000, 5 pages.
Veeder-Root, "Mag Inventory Measurement Probe," from <http://www.veeder.com/dynamic/index.cfm?Pageld=103>, by May 2005, 2 pages.
Veeder-Root, "Mag Plus Inventory Measurement Probe," from <http://www.veeder.com/dynamic/index.cfm?Pageld=274>, by May 2005, 2 pages.
MTS Systems Corp. USA, "How They Work, Magnetostrictive Linear Position Sensors," from <http://www.sensorland.com/HowPage024.html>, by May 2005, 3 pages.
Brochure entitled "Best-In-Class Tank Gauge Innovation," OPW Fuel Management Systems, Oct. 2007. 4 pages.

* cited by examiner

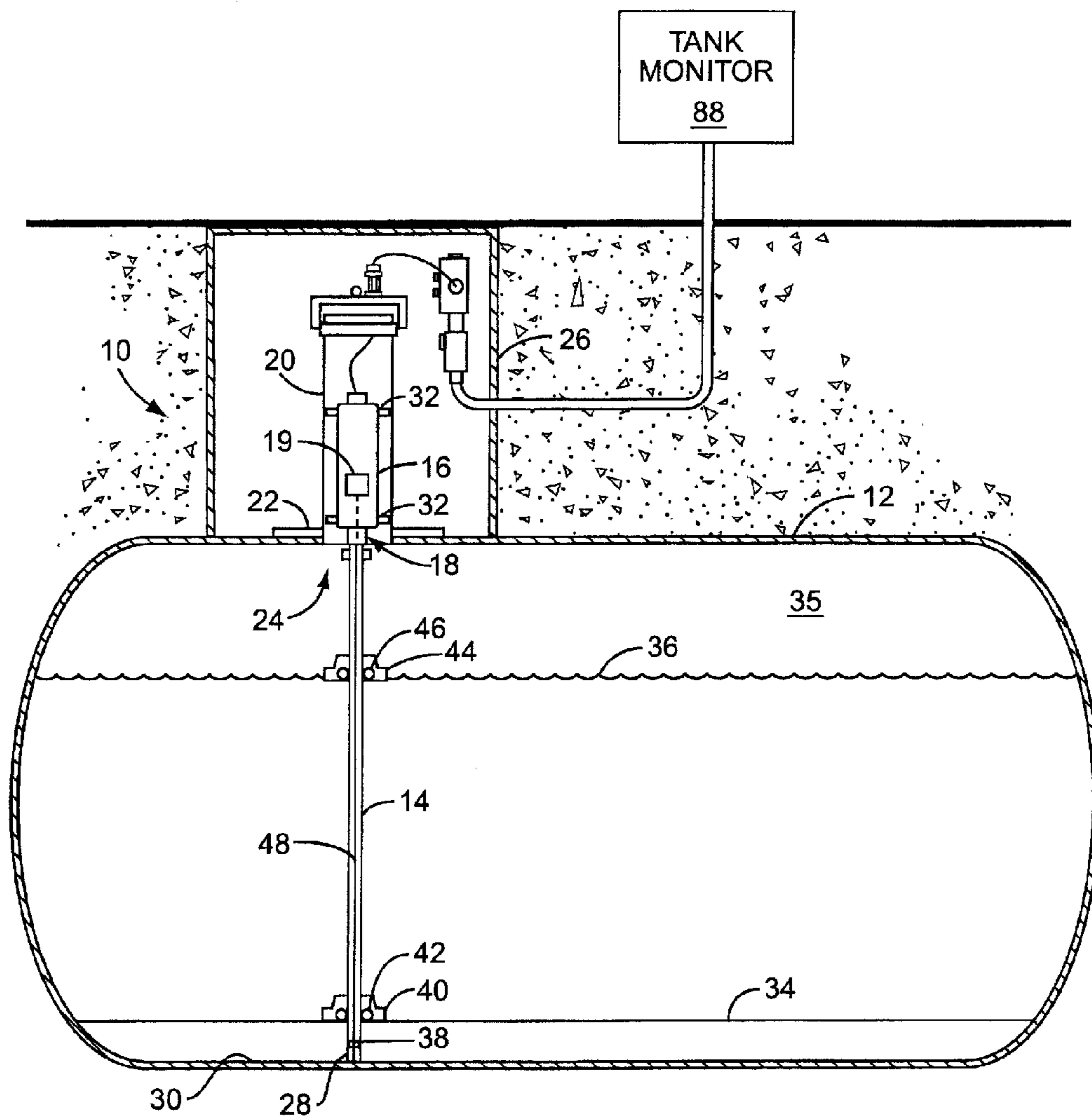


FIG. 1
PRIOR ART

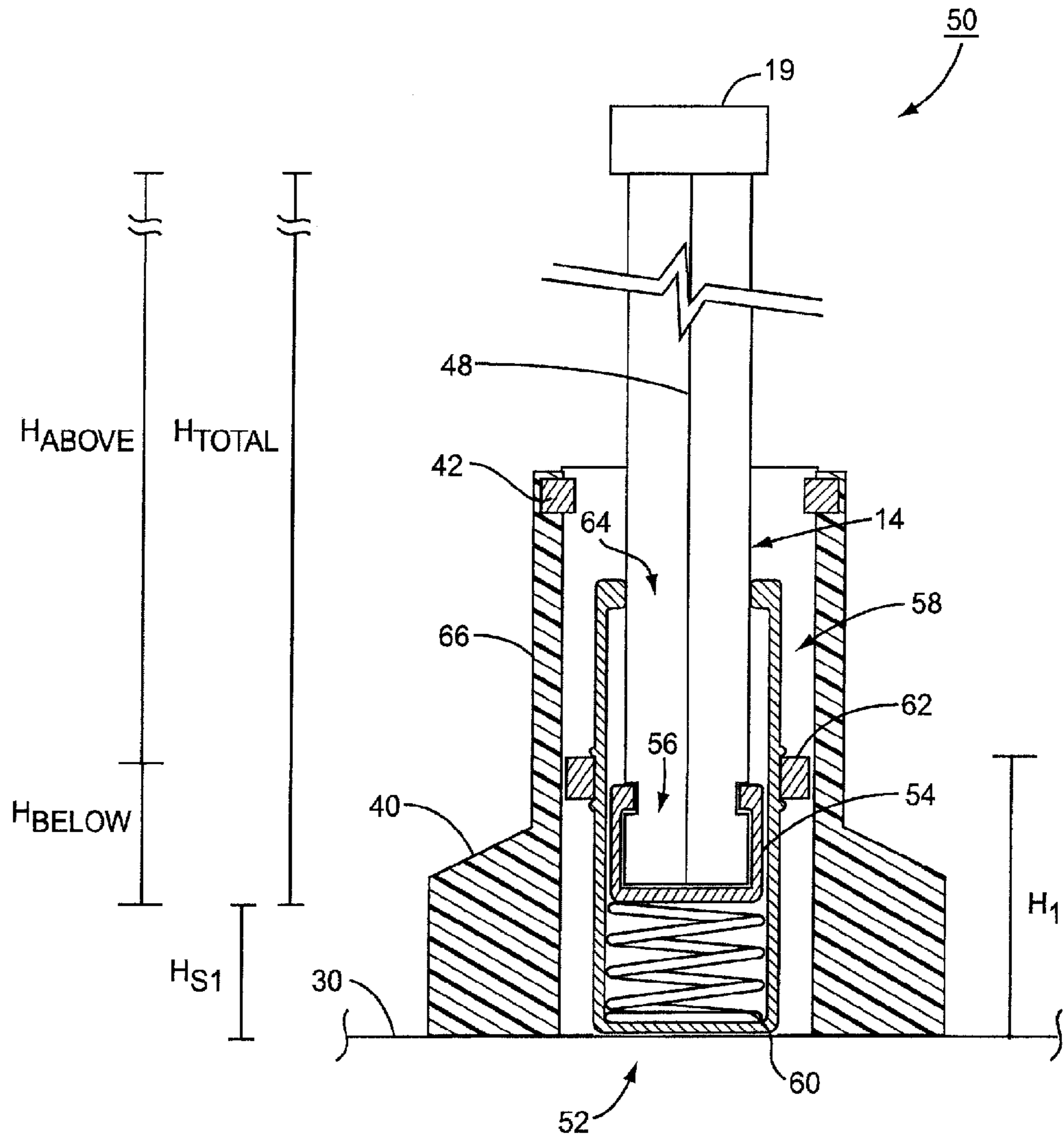


FIG. 2

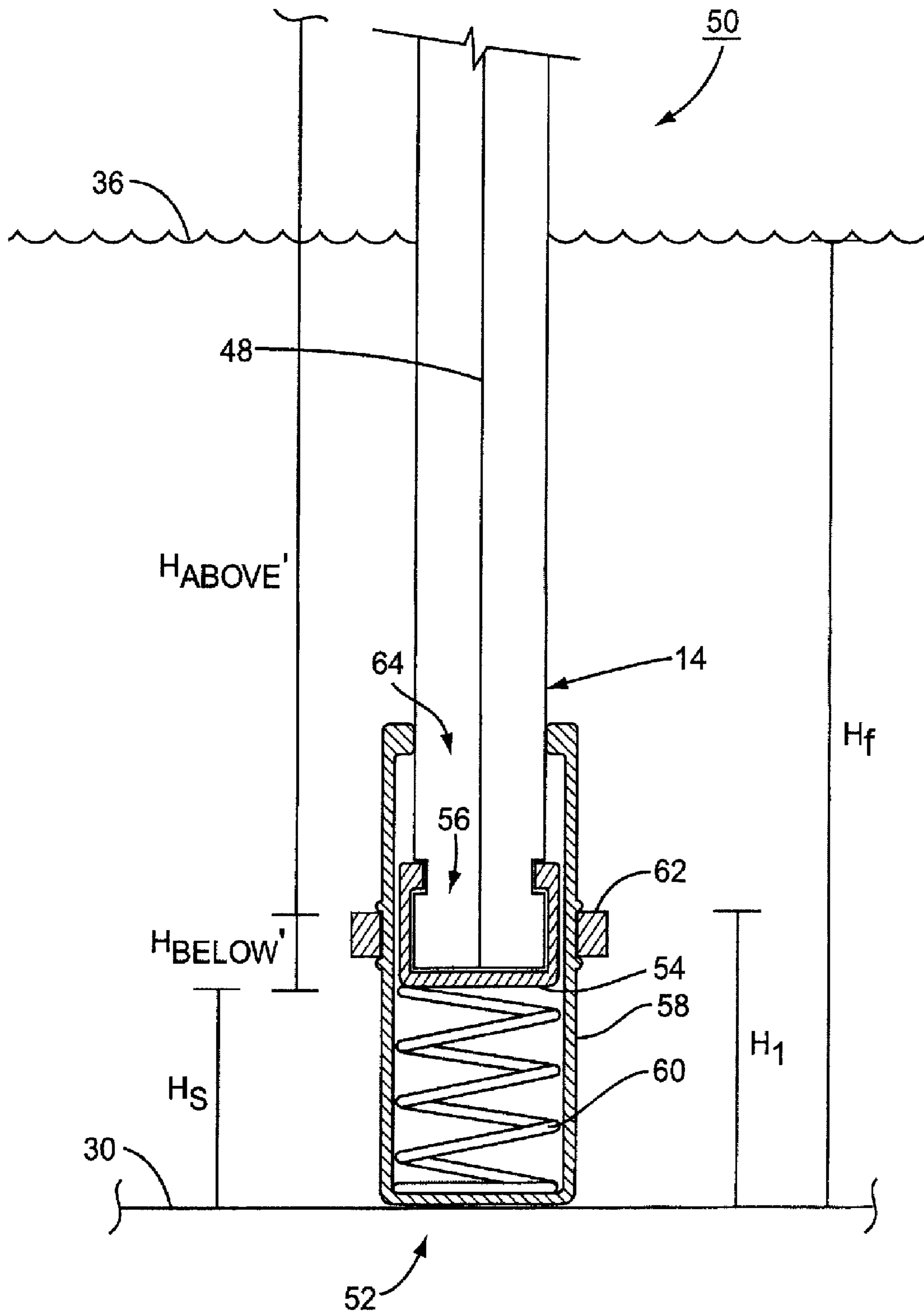


FIG. 3

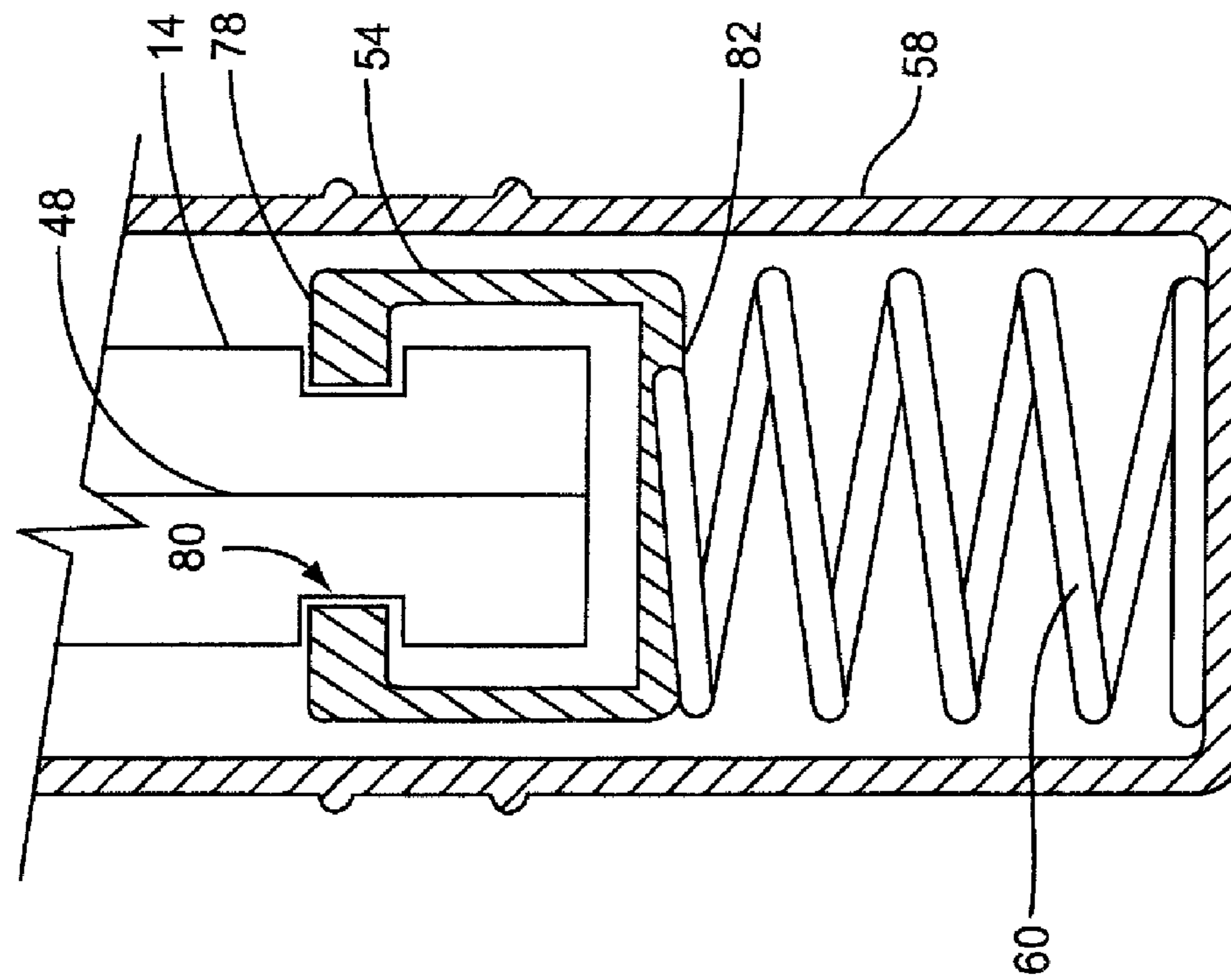


FIG. 5

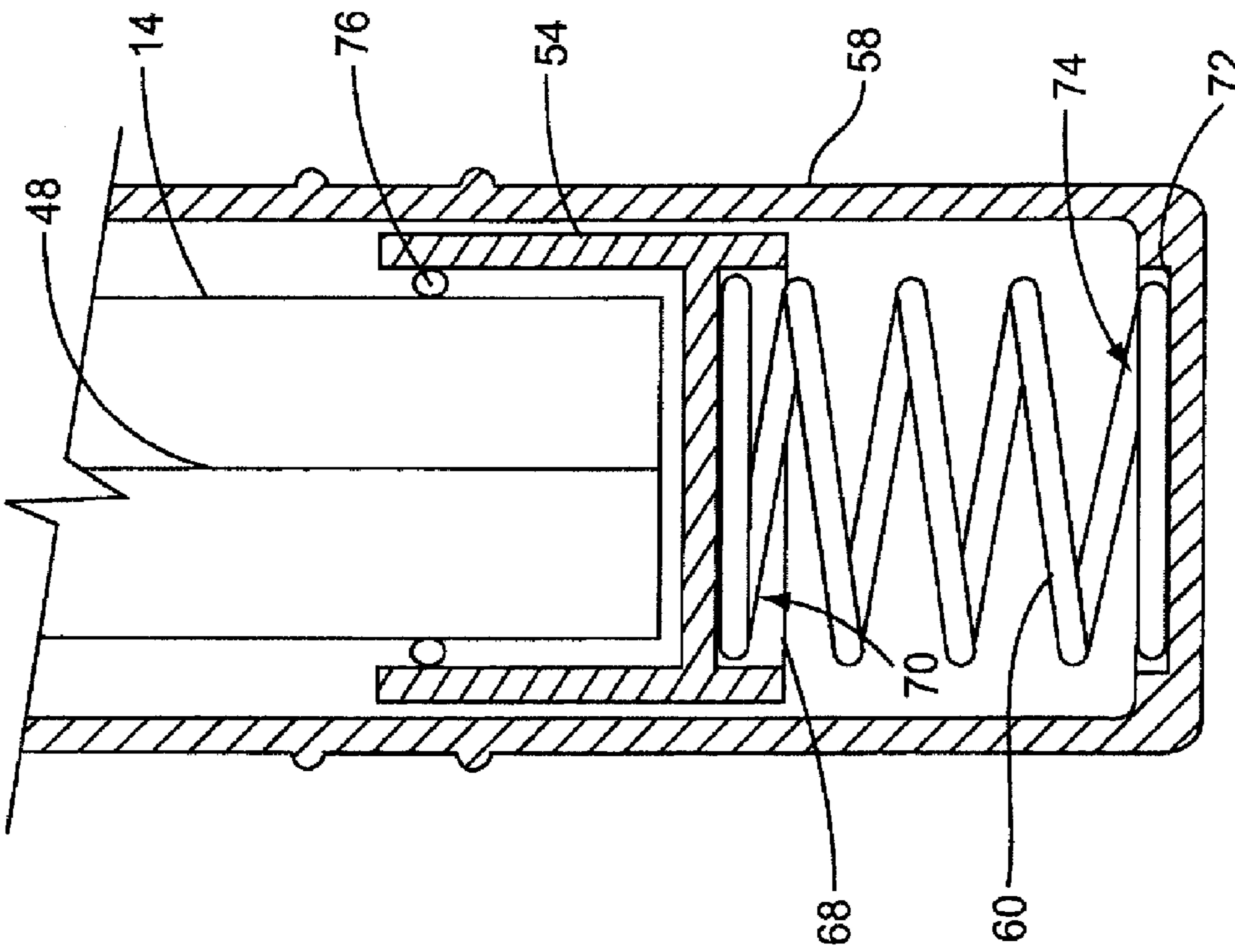


FIG. 4

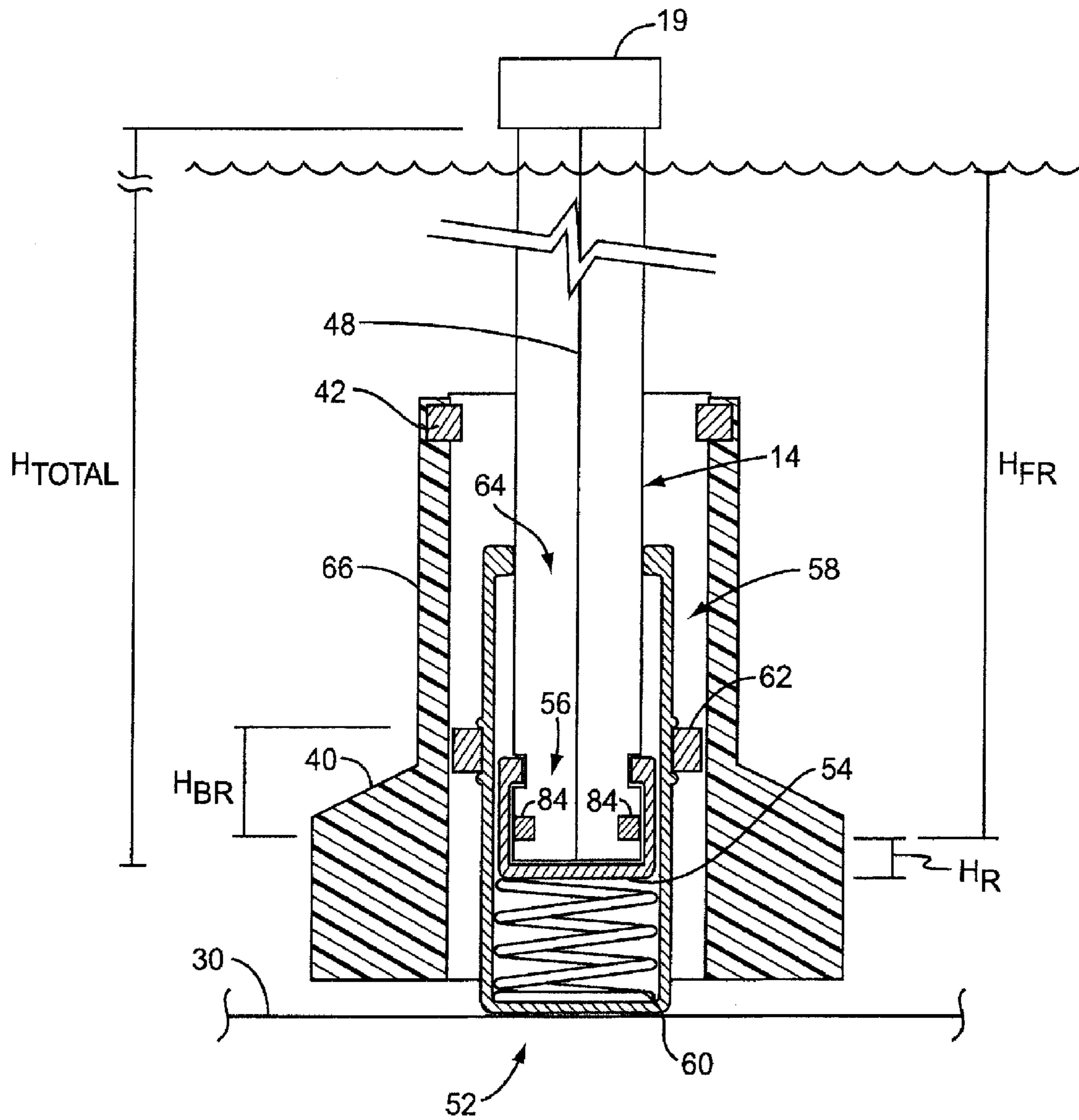


FIG. 6

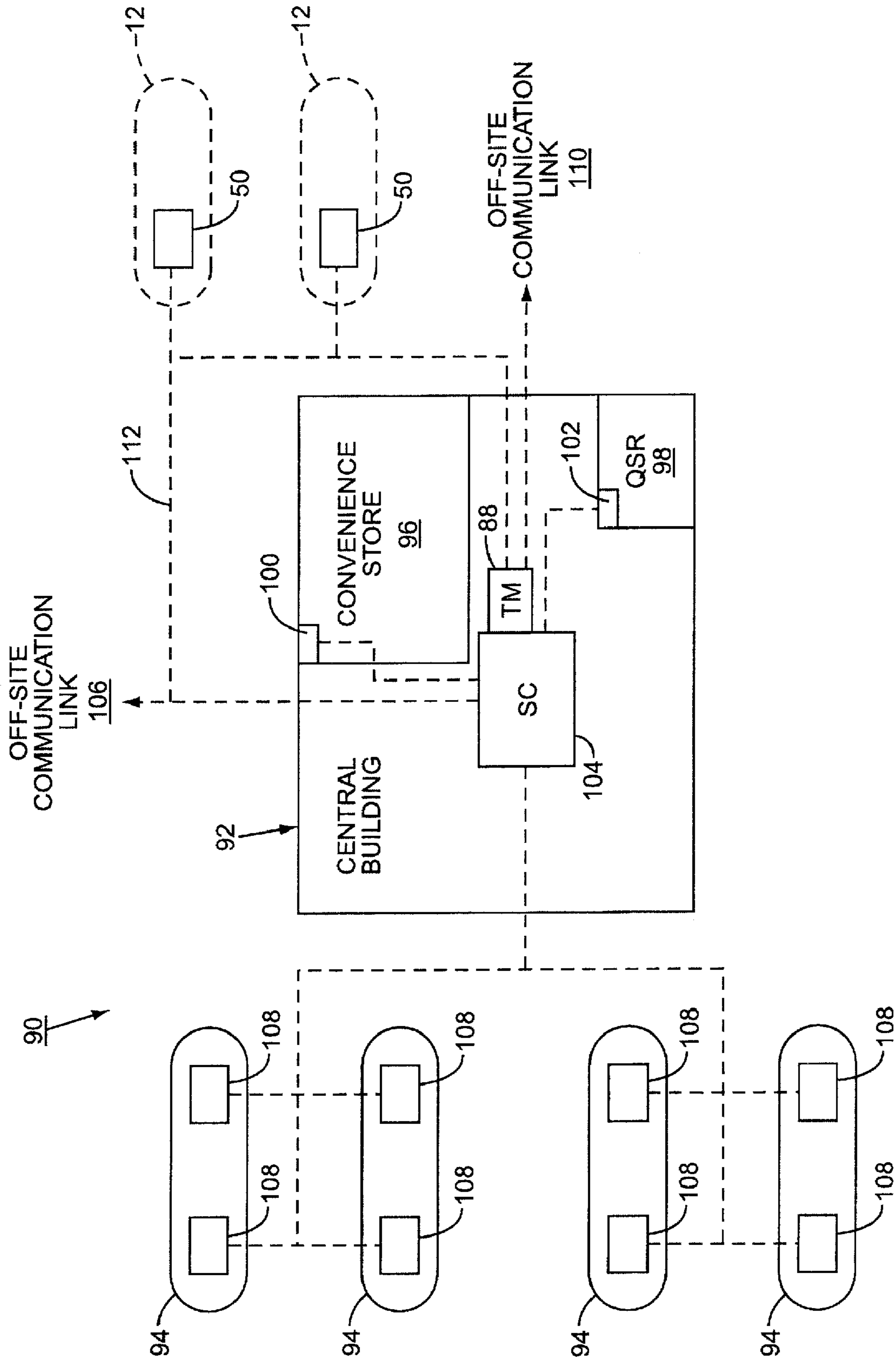


FIG. 7

**METHOD USING MAGNETOSTRICTIVE
PROBE BUOYANCY FOR DETECTING FUEL
DENSITY**

FIELD OF THE INVENTION

The present invention relates to a probe device, system, and method used in a fuel storage tank that can be used to determine the density of the fuel stored within the fuel storage tank.

BACKGROUND OF THE INVENTION

Fueling environments typically store fuel in large storage tanks located beneath the ground, sometimes referred to as “underground storage tanks” (UST). To comply with environmental laws, rules, and regulations, these storage tanks may be double-walled and equipped with various leak detection sensors and inventory reconciliation systems. One popular leak detection sensor is sold by Veeder-Root Company of 125 Powder Forest Drive, Simsbury, Conn. 06070, the assignee of the present application, under the name “The MAG Plus Inventory Measurement Probe” (Mag Probe). This probe is typically matched with a tank monitor, such as the TLS-350R, also sold by Veeder-Root Company. Such probes measure a height of fuel within the storage tank and may optionally measure a height of water (if present). The measurements are reported to the tank monitor for usage by the operator of the fueling environment to evaluate and reconcile fuel inventory and/or detect leaks, as is well understood.

While the United States has many rules and regulations relating to leak monitoring within fueling environments, other locales have additional requirements for fueling environments. For example, countries such as India and Russia have seen a rise in fraud at fueling environments, and have consequently taken steps to combat such fraud. Specifically, these countries have become aware that dilution of the fuel within storage tanks may be used as a technique to defraud a customer. One way in which the diluted fuel is created is through the addition of alcohol to the fuel storage tank. The alcohol allows the water at the bottom of the fueling tank to mix with the fuel, and the diluted mixture is then dispensed as normal through the fuel dispensers.

To combat this fraud, some governments have mandated that fuel density be measured. If the density is outside of a predetermined allowable range, it may be inferred that the fuel has been adulterated. Even if some countries or governments do not have such legislation requiring measurement of density of fuel, some fuel distribution companies that operate service stations may nonetheless find it desirable to monitor the density of their fuel for quality control purposes.

Density measurements also assist in calculation of the mass of fluid within a storage container. Differences in mass may be used to perform leak detection for fluids in situations where normal volume detection techniques are inadequate (e.g., waste oil storage containers). These situations create additional demand for density measuring devices.

All the devices currently known to be available commercially that are capable of measuring fuel density in a conventional fueling environment fuel storage tank are stand alone peripherals, requiring their own power and interface connections. Furthermore, these devices tend to have a limited range of values over which fuel density can be measured. Such stand alone peripherals are not desirable as a result of these deficiencies.

An additional concern that arises in the measurement of fuel density is that the density of the fuel is not typically uniform at all fuel levels in an underground storage tank. For

example, there may be thermal stratification which results in non-uniform densities at particular levels within the fuel storage tank. Likewise, surface thermal effects can be large. That is, when the surface of the fuel is much warmer than the bulk of the stored fuel, the density of the surface fuel relative to the bulk of the fuel is reduced. If the density of the fuel is measured just at the surface, the measurement will not accurately reflect the density of the bulk of the fuel. Any density measuring device should be able to address these issues.

In response to these concerns, the Assignee of the present invention presented the fuel density measurement system of commonly-owned U.S. patent application Ser. No. 11/048,145, filed Feb. 1, 2005. While the '145 Application provides one solution to the concerns raised above, there remains a need for a simpler solution.

SUMMARY OF THE INVENTION

The present invention is an improvement on a conventional fuel level probe that measures the height of fuel in a fuel storage tank. Specifically, the present invention is a magnetostrictive probe which has a probe shaft with a moveable foot on the terminal end of the probe shaft. The foot has a reference magnet whose position relative to the bottom of the fuel storage tank is fixed. The foot also includes an internal spring that allows the probe to move up and down within the foot as a function of the buoyancy of the probe shaft. The buoyancy of the probe shaft is a function of the height of the fuel that buoys the probe and the density of the fuel in which the probe shaft is placed. Other directly measurable or calculable variables may also contribute to the buoyancy of the probe shaft, and the algorithms of the present invention compensate for these other variables in the calculation of the fuel density. Based on the position of the probe shaft relative to the reference magnet, the height of the fuel, the spring constant of the internal spring, and other measurable or known variables, the density of the fuel may be derived and used as needed.

In operation, the present invention sends a current down a magnetostrictive wire within the probe shaft. The current in the magnetostrictive wire interacts with the reference magnet and introduces a torsional wave in the wire which is detected by the probe. The time elapsed between the signal generation and the arrival of the torsional wave may be used to measure the distance from the probe to the magnet. As the probe moves up and down within the foot as a function of the buoyancy, the distance measured will change and thus, the probe can measure the buoyancy of the probe shaft. In effect, the density of the fuel may be derived from the measured buoyancy of the probe shaft. The probe may either perform the calculations to arrive at the density of the fuel or may report its measurements to a tank monitor or other controller so that the controller may perform the calculations to determine the density of the fuel.

In one structural embodiment, the probe includes a probe canister attached to a probe shaft. The probe shaft has a terminal end and is designed to be inserted into the fuel storage tank. A foot is secured to the terminal end of the probe shaft. The foot includes an inner cup that fits over the probe shaft and an outer cup that the inner cup and probe shaft fit within. The reference magnet is secured fixedly to the outer cup. A spring is positioned between the two cups. Initially, the outer cup rests on the bottom of the fuel storage tank, and the full weight of the probe compresses the spring between the cups.

As fuel is introduced into the fuel storage tank, the fuel causes the probe to “float,” thereby reducing the compression of the spring. Thus, the probe shaft moves up and down within the outer cup. The force exerted upwardly by the spring is

equal to the weight of the probe minus the buoyancy of the probe. Because the reference magnet is fixed and the probe shaft floats relative to the reference magnet, it is possible to determine how much of the probe shaft is positioned above the reference magnet. That is, when a current is generated in the magnetostrictive wire within the probe shaft, the time elapsed between current generation and the arrival of the torsional wave generated by the reference magnet will allow calculation of the amount of the probe shaft above the reference magnet. The amount of the probe shaft above the reference magnet is then used in another calculation, along with the spring constant and the volume of the probe shaft, to arrive at the density of the fuel.

Those skilled in the art will appreciate the scope of the present invention and realize additional aspects thereof after reading the following detailed description of the preferred embodiments in association with the accompanying drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawing figures incorporated in and forming a part of this specification illustrate several aspects of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 illustrates a conventional magnetostrictive probe positioned in a fuel storage tank;

FIG. 2 illustrates a probe according to a first embodiment of the present invention;

FIG. 3 illustrates the probe of FIG. 2 inserted into a fuel storage tank with fuel therein such that the probe is buoyed upwardly;

FIG. 4 illustrates a first embodiment of the cups of the foot of the probe;

FIG. 5 illustrates a second embodiment of the cups of the foot of the probe where the spring is secured to the inner cup;

FIG. 6 illustrates a second embodiment of the probe of the present invention; and

FIG. 7 illustrates a fueling environment incorporating the probe of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The embodiments set forth below represent the necessary information to enable those skilled in the art to practice the invention and illustrate the best mode of practicing the invention. Upon reading the following description in light of the accompanying drawing figures, those skilled in the art will understand the concepts of the invention and will recognize applications of these concepts not particularly addressed herein. It should be understood that these concepts and applications fall within the scope of the disclosure and the accompanying claims.

The present invention is a fuel level probe that measures fuel density as well as fuel height in a fuel storage tank. An exemplary fuel level probe is a magnetostrictive probe which has a probe shaft with a moveable foot on the terminal end of the probe shaft. The foot has a reference magnet whose position relative to the bottom of the fuel storage tank is fixed. The foot also includes an internal spring that allows the probe to move up and down within the foot as a function of the buoyancy of the probe shaft. The buoyancy of the probe shaft is a function of the density of the fuel in which the probe shaft is placed. Other directly measurable or calculable variables, such as the fuel height, may also contribute to the buoyancy of the probe shaft, and the algorithms of the present invention

compensate for these variables in the calculation of the fuel density. In operation, the present invention sends a current down a magnetostrictive wire within the probe shaft. The current in the magnetostrictive wire interacts with the reference magnet and introduces a torsional wave in the wire which is detected by a sensor in the probe. The time elapsed between the signal generation and the arrival of the torsional wave may be used to measure the distance from the sensor to the magnet. As the probe moves up and down within the foot as a function of the buoyancy, the distance measured will change and thus, the probe can measure the buoyancy of the probe shaft. The density of the fuel is then derived from this measurement. The probe may either perform the calculations to arrive at the density of the fuel or may report its measurements to a tank monitor or other controller so that the controller may perform the calculations to determine the density of the fuel. The density of other fluids may also be measured with the probe of the present invention and the invention is not strictly limited to use in a fueling environment.

Because the present invention relates closely to a magnetostrictive fuel level probe, a discussion of a conventional magnetostrictive fuel level probe **10** (hereinafter "probe") is first presented herein with reference to FIG. 1, and the discussion of the present invention follows beginning with reference to FIG. 2 below.

The probe **10** is a magnetostrictive probe, such as the MAG PROBE™ magnetostrictive probe sold by the assignee of the present invention, namely Veeder-Root Company of 125 Powder Forest Drive, Simsbury, Conn. 06070 (see, for example, <http://www.veeder.com/dynamic/index.cfm?PageID=103> and <http://www.veeder.com/dynamic/index.cfm?PageID=274>). The probe **10** is positioned partially in a fuel storage tank **12**. Specifically, the probe includes a probe shaft **14** that extends into the fuel storage tank **12** while a canister **16** is positioned outside of the fuel storage tank **12**. The canister **16** is attached to the probe shaft **14** via fittings **18**. The canister **16** includes electronics **19**, which enable operation of the probe **10** as further explained below.

During installation, the probe **10** is lowered into the fuel storage tank **12** through a riser pipe **20** that is secured to the fuel storage tank **12** with a flange **22**. The riser pipe **20** is typically a four inch (10.16 cm) pipe. The fuel storage tank **12** has an aperture **24** therein that fluidly couples the interior of the riser pipe **20** with the interior of the fuel storage tank **12** and through which the probe shaft **14** extends. The riser pipe **20** may be positioned within a sump **26** (illustrated) or not (not illustrated) as needed or desired. The probe shaft **14** goes through the aperture **24** and a terminal end **28** of the probe shaft rests on the bottom **30** of the fuel storage tank **12**. The weight of the probe **10** keeps the terminal end **28** on the bottom **30**. The canister **16** is not secured to the riser pipe **20**, but may be spaced from the sides of the riser pipe **20** by one or two spacers **32**. It should be appreciated that the spacer(s) **32** may restrict horizontal movement of the canister **16**, but does not materially restrict vertical movement of the canister **16**.

In use, most fuel storage tanks, such as fuel storage tank **12**, have a small amount of water therein. This water collects at the bottom of the fuel storage tank **12**, forming a water-fuel interface **34**. The fuel sits on top of the water and has an air-fuel interface **36** at the ullage **35** of the fuel storage tank **12**. The probe shaft **14** extends through both interfaces **34** and **36**. The probe shaft **14** has a reference magnet **38** positioned proximate a terminal end **28** of the probe shaft **14** at a fixed, known distance from the terminal end **28**. The reference magnet **38** may be positioned internal to the probe shaft **14** as is conventional, or externally in a boot (not shown) that slips

over the end of the probe shaft **14**. A water level float **40**, typically an annular float, is positioned on the probe shaft **14** and floats at the level of the water-fuel interface **34**. A water level magnet **42** is associated with the water level float **40** so that the level of the water in the fuel storage tank **12** can be ascertained.

A fuel level float **44**, also generally an annular float, is positioned on the probe shaft **14** and floats at the air-fuel interface **36**. A fuel level magnet **46** is associated with the fuel level float **44** so that the level of the fuel in the fuel storage tank **12** can be ascertained. It should be appreciated that the floats **40** and **44** move freely up and down the probe shaft **14** as the respective levels of fluids (water and fuel) change. Likewise, the buoyancy of the floats **40** and **44** is determined by the fluid on which they will be floating. Such parameters are conventional and well understood by someone of ordinary skill in the art. However, the interested reader is directed to the MAG 1 & 2 PLUS! PROBES ASSEMBLY GUIDE, published by Veeder-Root, which is available online at [http://vrnotesweb1.veeder.com/vrdocrep.nsf/Files/577013-764/\\$File/577013-744.pdf](http://vrnotesweb1.veeder.com/vrdocrep.nsf/Files/577013-764/$File/577013-744.pdf), and is submitted as part of an Information Disclosure Submission accompanying this application at the time of filing. The ASSEMBLY GUIDE is hereby incorporated by reference in its entirety.

To determine the fuel level and the water level within the fuel storage tank **12**, the probe **10** generates an electric current with a current source within the electronics **19** positioned in the canister **16** and sends the electric current down a magnetostrictive wire **48** in the probe shaft **14**. Then, the probe **10** detects torsional wave reflections induced by the magnets **42** and **46** of the floats **40** and **44** respectively and the reference magnet **38**. The torsional wave reflections are detected with a detector such as a sensing coil (not shown explicitly) of the electronics **19**. The first reflection to arrive at the detector is a reflection from the fuel level magnet **46** associated with the fuel level float **44**. The second reflection to arrive at the detector is a reflection from the water level magnet **42** associated with the water level float **40**. A third reflection arrives from the reference magnet **38**. Since the speed of the torsional wave in the magnetostrictive wire **48** is known (typically about 3000 m/s), it is possible to calculate the distance between the detector and the magnet that induced the torsional wave. The detector thus measures the time elapsed between the origination of the pulse and the arrival of each torsional wave reflection. If the distance from the detector to a particular magnet is known, it is a well known exercise to determine the level of that particular magnet within the fuel storage tank **12**. Alternatively, the difference in arrival times of torsional waves is used to measure the distance between the level magnets and the reference magnet **38**. That is, the distance from the bottom **30** to the reference magnet **38** (the height of the reference magnet) is known (typically about one-half inch (~1.25 cm)) at the time of manufacturing. By measuring the time difference between arrival of torsional waves from, for example, the water level magnet **42** and the reference magnet **38**, the distance between the two magnets **38** and **42** may be determined. Specifically, the velocity of the torsional wave is multiplied by the time, and a distance is generated. This distance is added to the height of the reference magnet and from this calculation, the height of the water level magnet **42** is determined. Similar calculations may be made for the fuel level magnet **46**. Put another way, the heights of the magnets relative to the bottom of the fuel storage tank **12** are determinable.

The probe **10** reports the measured reflections to a tank monitor **88**, such as the TLS-350R manufactured and sold by Veeder-Root Company. The tank monitor **88** uses the data

from the probe **10**, and specifically, the measured reflections to determine the level and thus, the volume of fuel, within the fuel storage tank **12**. For example, the tank monitor **88** may determine a volume of fuel within the fuel storage tank from the height of the fuel level, as determined by the height of the fuel level float **44** (and as measured by the first reflection or its relationship to the reference magnet's **38** reflection). From this height, a conventional tank strapping algorithm or other conventional technique may be applied, as is well understood in the art, to convert the fuel level to arrive at the volume of fuel within the fuel storage tank **12**. For more information on the operation of a magnetostrictive fuel level probe, the interested reader is referred to U.S. Pat. No. 5,076,100, which is hereby incorporated by reference in its entirety.

The modified probe **50** (hereinafter "probe"), in accordance with one embodiment of the present invention, is illustrated in FIG. 2. In general, the probe **50** has components that are substantially similar to the components of the probe **10**. As such, where the component is identical to the component of probe **10**, the same number is used. FIG. 2 illustrates a modified foot **52** of the probe **50**. The modified foot **52** includes an inner cup **54** that may, in an exemplary embodiment, snap fit over a terminal end **56** of the probe shaft **14**. An outer cup **58** fits over the inner cup **54** and sandwiches a spring **60** between the inner cup **54** and the outer cup **58**. In particular, the spring **60** is positioned between an outer bottom surface of the inner cup **54** and an inner floor surface of the outer cup **58**.

The outer cup **58** also has a reference magnet **62** fixedly attached to an outer surface of the outer cup **58**. In an exemplary embodiment, the reference magnet **62** is an annulus and fits around the circumference of the outer cup **58**. Other arrangements are possible. For example, the reference magnet **62** could be positioned inside the outer cup **58** and does not have to be an annulus. Such permutations on the position and shape of the reference magnet **62** are within the scope of the present invention. A lower portion **64** of the probe shaft **14** is positioned within the outer cup **58** and moves up and down within the outer cup **58** as will be explained in greater detail below.

The water level float **40** fits over the modified foot **52** and the probe shaft **14**, and may include an extended neck **66**. The extended neck **66** spaces the water level magnet **42** from the reference magnet **62** so that torsional waves introduced by the magnets **42** and **62** may be differentiated by the detector within canister **16**. Empirical evidence indicates that approximately one inch (2.54 cm) should exist between the two magnets **42** and **62** for discrimination therebetween. It should be appreciated that the size of the modified foot **52** is designed such that the modified foot **52** does not interfere with the movement of the water level float **40**.

As is illustrated in FIG. 2, an outer bottom surface of the outer cup **58** rests on the bottom **30** of the fuel storage tank **12**. The weight of the probe **50** keeps the outer cup **58** firmly positioned on the bottom **30**. Thus, the position of the reference magnet **62** relative to the bottom **30** of the fuel storage tank **12** is fixed. Even if some geologic force or other event changes the shape of the fuel storage tank **12**, the distance between the reference magnet **62** and the bottom **30** will be H_1 , as illustrated in FIG. 2.

FIG. 2 illustrates the probe **50** when it is first inserted into an empty fuel storage tank **12**. That is, there is no fluid within fuel storage tank **12**. As a result, the full weight (W_p) of the probe **50** is positioned above the spring **60** and compresses the spring **60**. Under normal operating conditions, the weight of the probe **50** is constant. The spring **60** has a spring constant K_s . K_s is chosen such that the spring **60** is not fully com-

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pressed when the full weight W_p of the probe **50** acts on the spring **60**. However, the weight of the probe **50** will compress the spring **60** away from its initial height H_{s0} to some reduced height H_{s1} . H_{s0} is known and H_{s1} can be calculated or measured as needed or desired.

To calculate H_{s1} , and thus ultimately determine the amount of the probe shaft **14** above the reference magnet **62**, the present invention first subtracts the amount of magnetostrictive wire **48** above (H_{ABOVE}) the reference magnet **62** from the known total length (H_{TOTAL}) of the magnetostrictive wire **48**. H_{TOTAL} is known a priori. Measuring the torsional wave induced in the magnetostrictive wire **48** by the reference magnet **62** provides an effective measurement of H_{ABOVE} . Subtracting H_{ABOVE} from H_{TOTAL} gives a measurement of the amount of magnetostrictive wire **48** below H_{BELOW} the reference magnet **62**. As the height of the reference magnet **62** is known, subtracting H_{BELOW} from H_1 gives a good approximation of the height of the loaded spring **60** H_{s1} . Mathematically, this is formulated as follows:

$$H_{s1} = H_1 - H_{BELOW}, \text{ where } H_{BELOW} = H_{TOTAL} - H_{ABOVE}$$

or

$$H_{s1} = H_1 - (H_{TOTAL} - H_{ABOVE})$$

Basic physics requires the weight of the probe **50** is equal to the amount of force that the spring **60** is exerting upwards against the probe **50**. Applying Hook's Law, the equation can be presented as follows:

$$K_s(H_{s0} - H_{s1}) = W_p$$

This formula may be used to calibrate the probe **50** when it is initially installed if needed or desired, since all the values should be known before installation.

When fluid is introduced into the fuel storage tank **12**, the fluid will exert a buoyant force on the probe **50**, in effect bearing some of the weight of the probe **50** and lifting this weight off the spring **60**. This buoyant force will allow the spring **60** to decompress from its compressed height of H_{s1} . This situation is shown in FIG. 3, with the water level float **40** removed for ease of comprehension.

As is readily seen in FIG. 3, the fuel positioned within the fuel storage tank **12** is bearing some of the weight of the probe **50**, causing the probe **50** to exert less force on the spring **60**, which in turn allows the spring **60** to expand such that it is at some variable height H_s . It is to be understood that the probe **50** would not be so buoyant as to remove all weight from the spring **60**. Thus, $H_s < H_{s0}$. The force of the spring **60** is now modeled by:

$$F_s = K_s(H_{s0} - H_s) = W_p - B_p, \text{ where } B_p \text{ is the buoyancy of the probe } \mathbf{50}.$$

The buoyancy of the probe **50** is a function of the volume of the probe **50** within the fuel and the density of the fluid within the fuel storage tank **12**. The spring-loaded modified foot **52** allows the probe **50** to rise and fall relative to the modified foot **52**, with the rising and falling being dependent on increasing and decreasing fuel density respectively and other variables. Each of the other variables is known or can be calculated. Based on this knowledge and these calculations, the density of the fuel (D_f) may be calculated. Stepwise, calculation of D_f is as follows:

$$F_s = W_p - B_p$$

$$B_p = D_f * V_p, \text{ where } V_p \text{ is the volume of the probe } \mathbf{50} \text{ in the fuel.}$$

The volume of the probe **50** within the fuel is readily calculated as the cross-sectional area of the probe **50** (A_p)

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multiplied by the height of the probe **50** within the fuel (H_p). Or, substituting into the equation above:

$$B_p = D_f * A_p * H_p$$

H_p can be calculated from the height of the fuel (H_f) minus the height of the spring **60** (H_s). The calculation of H_f is known from conventional fuel level probe technology. Substituting into the equation above:

$$B_p = D_f * A_p * (H_f - H_s)$$

If this equation is substituted back into the equation of the force of the spring **60**, the result is as follows:

$$K_s(H_{s0} - H_s) = W_p - D_f A_p (H_f - H_s)$$

Solving for D_f , the equation becomes:

$$D_f = \frac{W_p - K_s(H_{s0} - H_s)}{A_p(H_f - H_s)}$$

Thus, the movement of the probe **50** may be used to measure the density of the fuel within the fuel storage tank **12**. Likewise, this arrangement effectively measures the density of the fuel throughout the fuel storage tank **12**. In this manner, errors that might be caused by thermal stratification are reduced or eliminated. Likewise, any density variations that may result from surface thermal effects are averaged away such the density measurement reflects the average of the entire volume of fuel rather than merely a single layer of fuel within the fuel storage tank **12**.

While the embodiment of FIGS. 2 and 3 are fully functional, there are other variations of the present invention. For example, the placement of the spring **60** may be varied and/or the nature of the inner cup **54** attachment to the probe shaft **14** may be varied to accommodate differing engineering and/or design constraints. FIGS. 4 and 5 illustrate some of these variations.

In FIG. 4, a first variation in the placement of the spring **60** that helps inhibit lateral movement of the spring **60** is illustrated. Specifically, the inner cup **54** has an indentation **68** which is sized to receive a top end **70** of the spring **60**. The indentation **68** helps hold the spring **60** in a fixed lateral position within the outer cup **58**. The outer cup **58** may likewise have an indentation **72** that is sized to receive a bottom end **74** of the spring **60**. Again, the indentation **72** helps hold the spring **60** in a fixed lateral position within the outer cup **58**. By limiting the lateral movement of the spring **60**, the likelihood that the spring **60** becomes misaligned is reduced, and the functionality of the present invention is preserved. While the indentations **68** and **72** help reduce the lateral movement of the spring **60**, it is possible that the sizes of the inner cup **54** and the outer cup **58** are such that the lateral movement of the spring **60** is sufficiently constrained to stop misalignment of the spring **60**. Thus, the indentations **68** and **72** are optional, and are not central to the present invention.

FIG. 4 also illustrates a variation on the means of attaching the inner cup **54** to the probe shaft **14**. Specifically, the inner cup **54** may be held on the probe shaft **14** via an elastomeric o-ring **76**. The space between the inner cup **54** and the probe shaft **14** is small and the diameter of the elastomeric o-ring **76** is slightly greater than the space between the inner cup **54**, and the probe shaft **14**. The elastomeric o-ring **76** may be positioned on the probe shaft **14** and the inner cup **54** slipped over the probe shaft **14**, compressing the elastomeric o-ring **76** therebetween. The elastomeric o-ring **76** presses outwardly

against both the probe shaft **14** and the inner cup **54** holding the inner cup **54** in a desired position relative to the probe shaft **14**.

FIG. **5** illustrates alternate variations on the means of attaching. In place of the elastomeric o-ring **76**, the inner cup **54** may include a flange **78** that is adapted to snap fit within a recess **80** on the end of the probe shaft **14**. This variation more fixedly secures the inner cup **54** on the end of the probe shaft **14** than the o-ring embodiment, but may be more manufacturingly intense. Other mechanisms may be used to secure the inner cup **54** to the probe shaft **14** without departing from the scope of the present invention.

FIG. **5** also illustrates an alternate mechanism of the present invention to keep the spring **60** properly aligned. In this embodiment, the spring **60** is fixedly secured to the lower surface **82** of the inner cup **54**. Spring **60** may be secured to the lower surface **82** by positioning the spring **60** when the inner cup **54** is molded. Alternatively, the spring **60** may be welded to the inner cup **54**, or other technique as needed or desired, depending on the material used in the construction of the inner cup **54**. In an exemplary embodiment, the spring **60** is a non-magnetic, stainless steel spring, although other materials may be used if needed or desired. All materials should be chosen to withstand extended submersion in a petroleum based fluid.

FIG. **6** illustrates an alternate embodiment of the present invention that improves accuracy of the measurement by eliminating potential non-linearities in the measurements made by the probe **50** as better explained below, although it is more expensive to manufacture than the previous embodiments. Specifically, the embodiment of FIG. **6** adds a probe reference magnet **84** to the probe shaft **14**, preferably near the terminal end **56**. The probe reference magnet **84** introduces a torsional wave in the magnetostrictive wire **48** just as the other magnets **42**, **46**, and **62** do. Importantly, the probe reference magnet **84** creates an additional reference point against which the torsional waves from the other magnets **42**, **46**, and **62** may be compared rather than relying on just the receipt time of the torsional waves.

It has been noted that torsional wave velocity non-linearities may affect the distance measured by the movement of the torsional waves. Specifically, temperature variations may accelerate or slow the torsional wave over the length of the magnetostrictive wire **48**. Other similar non-linearities may also be present over the length of the magnetostrictive wire **48**. However, most of the non-linearities are relatively time-insensitive such that for a given measurement, all the torsional waves are subjected to the same non-linearities. The probe reference magnet **84** allows the torsional waves to be compared to a fixed reference point (namely, near the end of the magnetostrictive wire **48**) rather than simply measured by the sensor in the canister **16**. That is, the torsional wave from the reference magnet **62** may be compared to the torsional wave from the probe reference magnet **84**. Since the distance along the magnetostrictive wire **48** to the probe reference magnet **84** is known, the sensor may calculate a compensation factor for the non-linearities and apply the same compensation factor to the measurement for the torsional wave from the reference magnet **62**. Alternatively, rather than measure the total time of travel for the torsional wave, merely the time difference between the arrivals may be measured to calculate the distance between magnets.

As noted above, the addition of the probe reference magnet **84** adds complexity to the probe **50**. Additionally, the magnets **42**, **62**, and **84** must be spaced far enough apart to differentiate therebetween. As noted above, it has been empirically determined that approximately one inch (2.54 cm) is required so

that the torsional waves do not merge and can be differentiated from one another. While shown positioned inside the probe shaft **14**, the probe reference magnet **84** could be fixed outside of the probe shaft **14** or fixed to the inner cup **54**.

The calculations to derive the fuel density for this embodiment are slightly more complicated than those presented above and are presented below.

As indicated above H_{TOTAL} is the length of the probe shaft **14**. In the exemplary embodiment, this is approximately equivalent to the distance (H_{PRM}) between the canister **16** and the probe reference magnet **84**. If the probe reference magnet **84** was not positioned at the terminal end of the probe shaft **14**, then $H_{PRM} < H_{TOTAL}$, but is still a known value. The probe reference magnet **84** is also some distance (H_R) above the bottom of probe **54**. As illustrated, the probe reference magnet **84** is positioned somewhere above the bottom of the probe **54**, and thus $H_R = H_{TOTAL} - H_{PRM}$. H_R is known at the time of manufacturing.

Two variables are measurable with the embodiment of FIG. **6**. The first variable is H_{BR} , which is equal to the height (vertical distance) between the reference magnet **62** and the probe reference magnet **84**. The second variable is H_{FR} , which is equal to the height (vertical distance) between the air-fuel interface **36** (as measured by the fuel float magnet **46**) and the probe reference magnet **84**. Solving for D_f now results in the following equation:

$$D_f = \frac{W_p - K_s(H_{BR} + H_{s0} + H_R - H_1)}{A_p(H_{FR} - H_R)}$$

It is possible that this equation may be restated, but such restatements are considered within the scope of the present invention.

FIG. **7** illustrates a fueling environment **90** that may incorporate the present invention, and includes the systems and devices that calculate and/or communicate the density of the fuel in the fuel storage tank **12** for the aforementioned purposes. Specifically, the fueling environment **90** may comprise a central building **92** and a plurality of fueling islands **94**.

The central building **92** need not be centrally located within the fueling environment **90**, but rather is the focus of the fueling environment **90**, and may house a convenience store **96** and/or a quick serve restaurant **98** therein. Both the convenience store **96** and the quick serve restaurant **98** may include a point of sale **100**, **102** respectively. The central building **92** may further house a site controller (SC) **104**, which in an exemplary embodiment may be the G-SITE® POS sold by Gilbarco Inc. of 7300 W. Friendly Avenue, Greensboro, N.C. 27410. The site controller **104** may control the authorization of fueling transactions and other conventional activities as is well understood. The site controller **104** may be incorporated into a point of sale, such as the point of sale **100**, if needed or desired. Further, the site controller **104** may have an off-site communication link **106** allowing communication with a remote location for credit/debit card authorization, content provision, reporting purposes, or the like, as needed or desired. The off-site communication link **106** may be routed through the Public Switched Telephone Network (PSTN), the Internet, both, or the like, as needed or desired.

The plurality of fueling islands **94** may have one or more fuel dispensers **108** positioned thereon. The fuel dispensers **108** may be, for example, the ECLIPSE® dispenser or the ENCORE® dispenser sold by Gilbarco Inc. The fuel dispensers **108** are in electronic communication with the site controller **104** through a LAN or the like.

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The fueling environment **90** has one or more fuel storage tanks **12** adapted to hold fuel therein. In a typical installation, fuel storage tanks **12** are positioned underground, and may also be referred to as underground storage tanks. Further, each fuel storage tank **12** has a liquid level probe, such as probe **50**. The probes **50** report to the tank monitor (TM) **88** associated therewith. Reporting to the tank monitor **88** may be done through a wire-based system, such as an Ethernet LAN, or a wireless system conforming to IEEE standard 802.11 g or the like, as needed or desired. The tank monitor **88** may communicate with the fuel dispensers **108** (either through the site controller **104** or directly, as needed or desired) to determine amounts of fuel dispensed, and compare fuel dispensed to current levels of fuel within the fuel storage tanks **12**, as needed or desired. In a typical installation, the tank monitor **88** is also positioned in the central building **92**, and may be proximate the site controller **104**.

The tank monitor **88** may communicate with the site controller **104**, and further may have an off-site communication link **110** for leak detection reporting, inventory reporting, or the like. Much like the off-site communication link **106**, the off-site communication link **110** may be through the PSTN, the Internet, both, or the like. If the off-site communication link **110** is present, the off-site communication link **106** need not be present, although both links may be present if needed or desired. As used herein, the tank monitor **88** and the site controller **104** are site communicators to the extent that they allow off-site communication and report site data to a remote location.

The present invention capitalizes on the off-site communication link **110** by forwarding data from the probe **50** to the remote location. This data should preferably be protected from tampering such that the site operator cannot alter the data sent to the remote location through either of the off-site communication links **106** or **110**. This tamper proof flow of data is provided so that the site operator, who presumably is the one who might be inclined to adulterate the fuel, does not have access to the data that reports on whether the fuel has been adulterated. The data from the probes **50** may be provided to a corporate entity from whom the site operator has a franchise, a governmental monitoring agency, an independent monitoring agency, or the like, as needed or desired. One way to prevent tampering is through an encryption algorithm.

An alternate technique that helps reduce the likelihood of tampering is the use of a dedicated off-site communication link **112**, wherein the probes **50** report directly to a location removed from the fueling environment **90**. In this manner, the operator of the fueling environment **90** does not have ready access to the dedicated off-site communication link **112**.

For further information on how elements of a fueling environment **90** may interact, reference is made to U.S. Pat. No. 5,956,259, which is hereby incorporated by reference in its entirety. Information about fuel dispensers **108** may be found in U.S. Pat. Nos. 5,734,851 and 6,052,629, which are hereby incorporated by reference in their entireties. For more information about tank monitors **88** and their operation, reference is made to U.S. Pat. Nos. 5,423,457; 5,400,253; 5,319,545; and 4,977,528, which are hereby incorporated by reference in their entireties.

Those skilled in the art will recognize improvements and modifications to the preferred embodiments of the present

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invention. All such improvements and modifications are considered within the scope of the concepts disclosed herein and the claims that follow.

What is claimed is:

1. A method of detecting fuel density for fuel within a fuel storage tank, comprising:
 - measuring, with a magnetostrictive fuel probe having a probe shaft, a distance associated with an amount of the probe shaft positioned above a reference magnet;
 - calculating a buoyancy associated with the probe shaft;
 - calculating from the buoyancy of the probe shaft, the fuel density for fuel within the fuel storage tank; and
 - reporting the fuel density to a location removed from the magnetostrictive fuel probe.
2. The method of claim 1, wherein measuring the distance associated with the amount of the probe shaft positioned above the reference magnet comprises allowing the probe shaft to move up and down within a spring-loaded foot associated with the magnetostrictive fuel probe.
3. The method of claim 2, wherein the probe shaft moves up and down within the spring-loaded foot as a function of the buoyancy of the probe shaft.
4. The method of claim 3, wherein calculating according to the algorithm comprises calculating a force exerted by a spring on the probe shaft, namely $F_s = K_s * (H_{s0} - H_s)$, wherein F_s is the force exerted by the spring, K_s is a spring constant of the spring, H_{s0} is an unloaded height of the spring, and H_s is a loaded height of the spring.
5. The method of claim 4, wherein calculating according to the algorithm comprises subtracting the force exerted by the spring on the probe shaft from the weight of the probe shaft, namely $W_p - K_s * (H_{s0} - H_s)$, where W_p is the weight of the probe shaft.
6. The method of claim 5, wherein calculating according to the algorithm comprises dividing a quantity of the weight of the probe shaft minus the force exerted by the spring by a volume of the probe shaft within the fuel, namely

$$D_f = \frac{W_p - K_s(H_{s0} - H_s)}{A_p(H_f - H_s)},$$

wherein A_p is a cross sectional area of the probe shaft and H_f is a height of the fuel within the fuel storage tank.

7. The method of claim 2, wherein measuring comprises, at least in part, measuring a time component associated with a torsional reflection.
8. The method of claim 2, wherein measuring comprises, at least in part, measuring a fuel depth with the magnetostrictive fuel probe.
9. The method of claim 2, wherein reporting the fuel density to a location removed from the magnetostrictive fuel probe comprises encrypting data from the magnetostrictive fuel probe such that it cannot be altered by a fueling site operator.
10. The method of claim 2, further comprising measuring a distance to a probe reference magnet associated with a terminal end of the probe shaft and comparing this distance to the distance associated with the amount of the probe shaft positioned above the reference magnet.

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